Modeling for Military Operational Medicine Scientific and Technical Objectives

Annual Report

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1. Introduction

1.1 Critical Issues

The US Army Medical Research and Material Command (USAMRMC) faces ever increasing pressure to answer more mission questions with less resources and time. The Catch-22 aspect is that problems cannot be satisfactorily solved at the moment they arise unless the supporting research basis has already been laid. Consequently, it is imperative to be proactive: anticipate need and put in place the broadest infrastructure of applied research that can be practically accomplished.

In addition to basic research programs, the USAMRMC has formulated a number of Scientific and Technical Objectives (STO) to achieve certain specific technical results over the next 3-5 years. By their nature and firm objectives, these programs are <u>applications</u> of the basic findings. Their goals, by and large, are to transition scientific findings into devices, treatments, procedures, or standards that can be used or applied in a military environment. In these programs, scientific breakthroughs are not planned, but high probability of a useful <u>product</u> is.

As of FY99, the Military Operational Medicine Research Program (MOMRP) has 13 STO programs proposed or active. These programs are designed to develop useful products in a wide range of military medicine areas from A (Laser Bioeffects and Treatment) to Z (Mass Properties of Head-Support Devices and Soldier Health). In each case the proposed product is based on promising results obtained in more basic research, which must be refined and validated in the less controlled environment of military operations.

To make the transition from the laboratory to the field, it is critical to take full advantage of the findings from the laboratory. Those findings are primarily in the form of experimental data, often collected under idealized conditions and perhaps in animal or surrogate models. Those data must be extrapolated to man in a military scenario in order to guide the device, treatment, procedure, or standard being developed by the STO.

Rapid, comprehensive data retrieval and analysis, coupled with mathematical modeling putting the results in the context of physiological and physical processes, are highly effective and often indispensable tools for achieving these goals. In some STOs (K, U, and Y), mathematical models are the product. In others (H and W), mathematical models and data analysis are specific components that will be used to achieve the desired product. In every STO data analysis and extrapolation play a critical role.

1.2 What is Needed

In each MOMRP STO, but particularly STO H, K, U, W, and Y, there is a need for mathematical models that capture the scientific findings of the underlying basic research and provide a product that can be used to meet the objectives of each respective STO. The models should be as complete and sophisticated as possible, yet be reliable enough to ensure that the final goals are met. These requirements suggest a program of incremental improvement, based on laboratory testing and more research-oriented mathematical modeling, and of practical design that expresses input and output in the framework of the particular application.

1.3 Technical Objective

The research program sponsored under contract DAMD17-00-C-0031 will provide the USAMRMC with data organization, mining, and knowledge management tools and with practical mathematical models that guide the effort in the MOMRP STOs. The approach is to define a "base" model that can be incrementally improved over the life of the STO. The successive model improvements are designed to meet the evolving requirements of each STO. A review and assessment of the literature and collection and organization of relevant data will proceed in step with the model development.

1.4 First Year's Accomplishments

The first modeling STO has been approved, STO-Y: Inhalation Injury and Toxicology Models. A multiyear effort will deliver a comprehensive assessment tool for acute exposure to toxic gases, particles, and aerosols generated in fires. A critical review of mechanisms, models, and data has been performed resulting in an overall structure for the model and a detailed plan for the modeling of the control of breathing. Laboratory experiments to fill in gaps in small animal ventilation response have been conceived, conducted, and the data reduced to a form for analysis. A first version of the software, TGAS, has been produced and the plan and first year's work has been peer-reviewed by the American Institute of Biological Sciences.

A second modeling STO on blunt trauma injury underwent peer review at the beginning of the year. Based on that review, the STO was revised and narrowed to a single blunt trauma mode. The effort is now called STO-K: Behind Armor Trauma Modeling and has been approved by the ASTWG. Work has been conducted analyzing previous animal test data, finite element models of armor-body impact, and the conceptual design of an impact-measuring device. A multiyear plan for developing a model-based assessment tool has been made, including parallel animal tests at WRAIR, that will be in FY02.

Work on the modeling STO-K1: Whole Body Blast Bioeffects continues. The Blast Test Site data is being organized into searchable databases of the documents, electronic form of the documents, and digitized form of the data. Transition of a new non-auditory component of the Military Standard 1474D is nearly complete, awaiting comments from the Center for Health Promotion and Preventative Medicine (CHPPM). Analysis of the auditory component of the Military Standard have been accepted for publication, although acceptance of changes by CHPPM are still in discussion.

Modeling and data support of STO-H: Warfighter Physiological Status Monitoring continues in an advisory mode only. Software support and data analysis of field tests have been produced and a unified plan for model development and validation made.

Jaycor support of STO-U: Fusion of Physiological Models has been requested by USARIEM. Software has been developed and delivered to USARIEM to assist in data analysis. Several datasets have been translated into General Data Interchange Format (GDIF) to take advantage of this software. Work on a simulation-based model of thermoregulation has begun that will allow the SCENARIO software to be expanded to include more physiological processes and merge with the physiologically based models being developed under STO-Y.

Modeling and data support of STO-W: Optimization of Physical Performance continues. An articulated modeling software toolbox has been developed and several applications in support of the USARIEM biomechanics laboratory have been developed. A portable data collector for ambulatory foot contact force measurement has been developed. Previous data from laboratory studies of biomechanics have been translated to GDIF format for ease of future analysis. A model-based assessment method for overuse injury modeling has been conceived that will complement the current STO-W effort.

Some of the products listed are provided to other researchers to assist their own projects and are not to be distributed until those researchers have a chance to publish their work. Those products are listed as [in review] or [internal use].

2. STO-H: Warfighter Physiological Status Monitoring

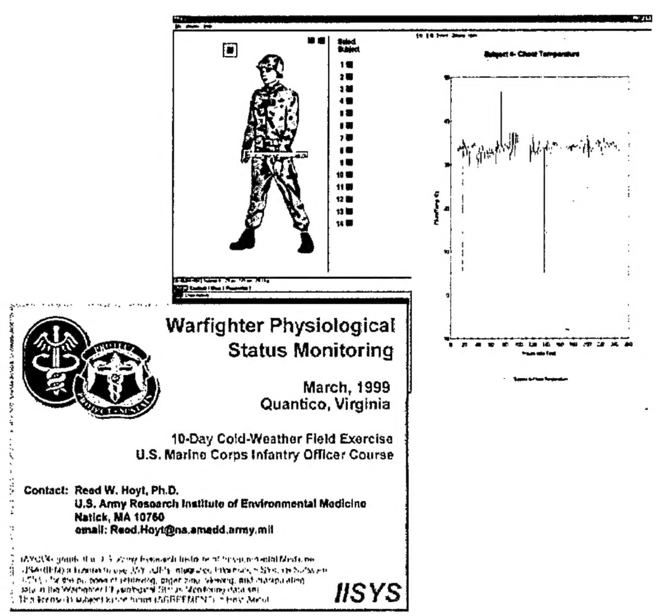
Jaycor supports the WPSM effort primarily in an advisory role to the STO Coordinator on technical matters, in particular, those involving modeling and data organization.

2.1 Support of WPSM IRT

Jaycor has participated in all of the Video Tele-Conferences (VTC) held by the IRT. In addition to participating in discussions, Jaycor was tasked to develop a strategic plan for developing and validating a unified model for WPSM. That plan also considered the integration of effort with other MOMRP supported STO efforts. Jaycor has identified other sources of multisensor gear being developed for the commercial physical fitness markets and for one candidate, BodyMedia®, has continued technical discussions on sensor and algorithm development. In January 2001, Jaycor attended the last IRT meeting at USARIEM and provided comments on risk mitigation strategies to the IRT Chairman.

2.2 March 1999 Field Study Database

The final IISYS session was delivered on August 18, 2000 for the March 1999 Quantico Study. It included data traces for each subject, database entries, activity logs, weather data, pictures and videos.

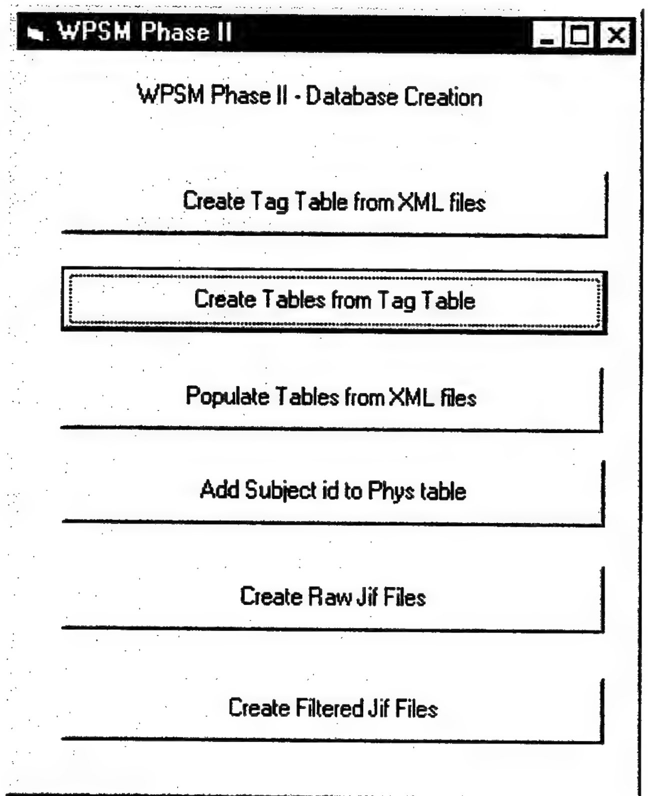


Screen images from IISYS context-based access to March 1999 Quantico Field Exercise. All data can be accessed by pointing and clicking on diagrams. Data can be cross-plotted between subjects and between studies an can be downloaded with other programs, such as MS Excel.

Product 1: March 1999 Field Study Database on CD

2.3 Conversion of XML format to GDIF

The WPSM project has adopted a scheme written in XML as the standard for storing and distributing data collected in instrumented field studies. The first study to use this format was the September 1999 Quantico exercise. There already exists a wide range of data analysis and retrieval tools build around the General Data Interchange Format (GDIF) and the previous cold weather study at Quantico in March 1999 has been converted to and organized in that format. Consequently, to make study-to-study comparisons and to take advantage of the analysis tools that already exist, software was written to translate the USARIEM XML format into GDIF. The conversion process identified elements missing from the XML-based scheme, such as units, and some ambiguities. These suggestions and findings were reported to Dr. Reed Hoyt at USARIEM, along with a complete data printout using the GDIF automatic plotting software.



GetTags software allows the user to read XML data files as formatted by USARIEM and generate relational databases in MS Access and generate time history data files in GDIF. Once in the GDIF format, a wide range of analysis programs can be used for further study.

Product 2: GetTags, Ver. 1.1 Software (2001).

Product 3: Long, D.W. (2001). "WPSM, Phase 11, September 1999 Data (Filtered)," Jaycor Report J2997.32-99-152. [internal use only]

Product 4: Long, D.W. (2001). "WPSM, Phase 11, September 1999 Data (As Received)," Jaycor Report J2997.32-99-153. [internal use only]

3. STO-K[1]: Whole-Body Blast Bioeffects

3.1 Organization of Blast Test Site Data

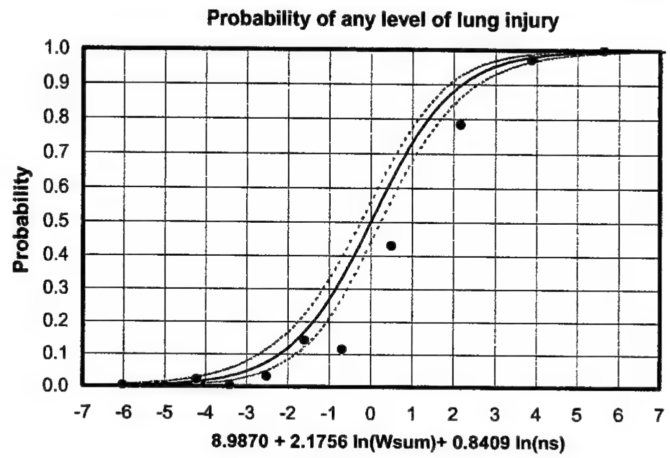
The government-sponsored research at the Blast Test Site generated 390 protocols, reports, and papers; collected 2286 critical secondary references; and produced data from more than 35 studies over a 40-year period. The purpose of this project is to collect, organize, and make available this vast collection of knowledge. During the past year a citation database has been completed with entries for all of the documents collected. The documents generated at the site have been digitally scanned into PDF format with hidden text, so that text searching can be conducted. The secondary references have been sent to Defense Technical Information Center (DTIC) to be crosschecked against their current document set, scanned, and added to their collection. When completed, the electronic form of these documents will be added to the MRMC collection. About 60% have been scanned by DTIC. Arrangements were made to ship to Jaycor 50 boxes of study data that was being stored at WRAIR from BOP studies and finally give us a complete data set. In support of STO-K[1], all data from the BOP studies will be digitized and then organized into a context-based data access system, using the IISYS program. Every data item (reports, log notes, photographs, necropsy sheets, pressure traces, etc.) is being sorted by the study, test, and animal, and then scanned electronically. In the process of reconciling the WRAIR, BTS, and Jaycor data sets it was discovered that better versions of the data were available, so many previously digitized items were rescanned. About 50% of the data has been processed.

Product 5. Martinez, Berlinda and Ives, B. J. (2001). "Blast Test Site Citation Database," Jaycor Report J2997.29-99-094R1.

Product 6. Martinez, Berlinda and Ives, B. J. (2001). "Blast Test Site Secondary Citation Database," Jaycor Report J2997.19-01-149.

3.2 Injury Correlate Analysis

As part of a joint MRMC-NHTSA working arrangement, Jaycor used the MRMC BOP injury database and the NHTSA biomechanics database to develop correlates for injuries arising from distributed traumatic loading (blast and airbags). The dominant injuries reported in these two databases are lung contusion and rib fracture. Backward step-wise elimination was used to determine the significant correlates and then to develop log-logistic regression to each injury mode. The results will be used by MRMC to refine the nonauditory component of the Military Standard and will be used by NHTSA to refine the impulsive thoracic injury criterion used in crash testing.



Regression of lung injury to total normalized work calculated by INJURY.

Product 7. Masiello, P.J. and Stuhmiller, J.H. (2000). "Impulsive Thoracic Injury Criteria," Jaycor Report J2997.53-00-105R1. [in review]

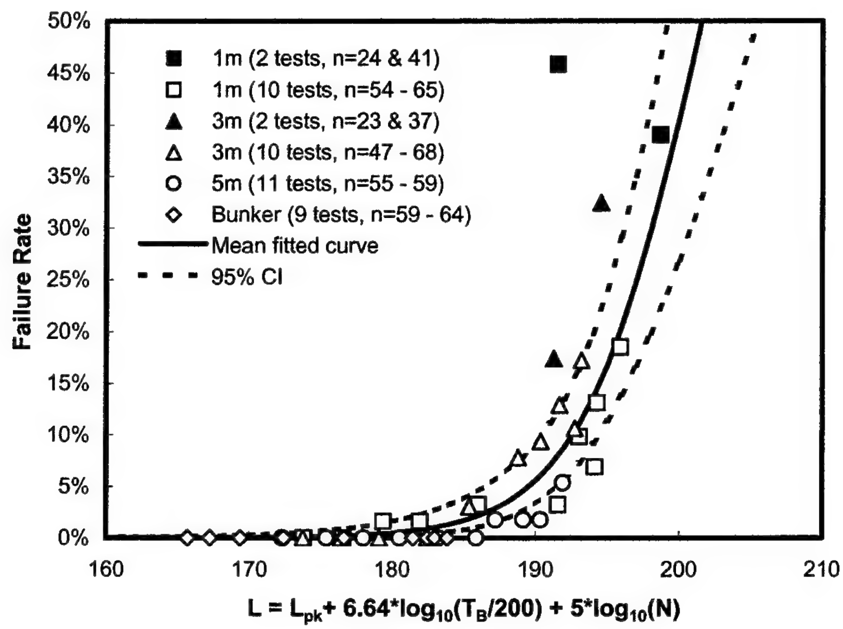
3.3 Risk Assessment Code (RAC) Automation

In the transition of the INJURY software to CHPPM for use in making Health Hazard Assessments (HHA) for impulsive noise, it was learned that INJURY provides only one component in the process of determining a Risk Assessment Code (RAC). Transition of the STO-K[1] product cannot occur until a RAC-determining methodology is provided. Jaycor worked with WRAIR staff making these assessments to understand the process and then to capture it in software. Several iterations of the software have been reviewed by MRMC and WRAIR and the last version has been sent to CHPPM for comment. After CHPPM input is received and incorporated, the methodology and software will be finalized, documented, and delivered.

Product 8: RAC software [in review]

3.4 Evaluation of Auditory Risk from BOP

Jaycor continues to support the MOMRP effort to upgrade the auditory injury portion of the Military Standard 1474D. This effort has involved collecting, organizing, and analyzing human volunteer data collected at the Blast Test Site under MRMC sponsorship. That analysis has resulted in quantifying the degree to which the current standard overestimates the threshold of injury. The primary accomplishment of the past year has been to get the work accepted for publication by the Acoustical Society of America, thereby moving forward the effort to have a revision to the Military Standard accepted by the auditory committee.



Correlation of all human volunteer data collected at the Blast Test Site with the current acoustic level parameter used by Military Standard 1474D. The analysis shows that 95/95 protection (95% protection of the population with 95% confidence) will be provided for the test population at acoustic levels 9 dB higher than the current standard.

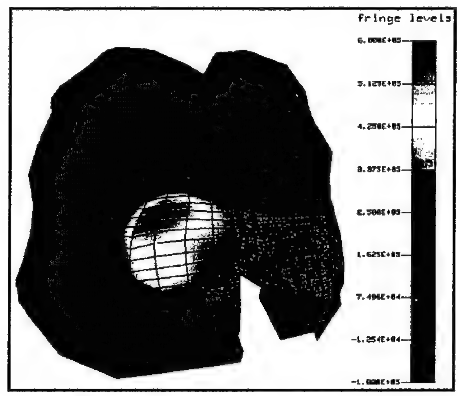
Product 9: Chan, P. C., K. H. Ho, et al. (2001). Evaluation of Impulse Noise Criteria Using Human Volunteer Data. Jaycor presentation to Int'l Military Noise Conference, Baltimore, Maryland, April 24-26, 2001.

Product 10: Chan, P.C., Ho, K.H., Kan, et al. (2001). "Evaluation of Impulse Noise Criteria Using Human Volunteer Data," J. Acoust. Soc. Am. 110(3), Pt. 1.

4. STO-K: Blunt Trauma Injury Models

4.1 Support of AIBS Review

In August 2000, the WRAIR program plans for developing injury models for a wide range of trauma (blast, nonlethal weapon impact, behind body armor, head injury from ballistic impact and car crashes) was reviewed by a panel convened by the American Institute of Biological Sciences (AIBS). Jaycor prepared a summary of biomechanical modeling used in previous blunt trauma programs on blast overpressure and nonlethal weapon impact and the planned contribution to the WRAIR program.



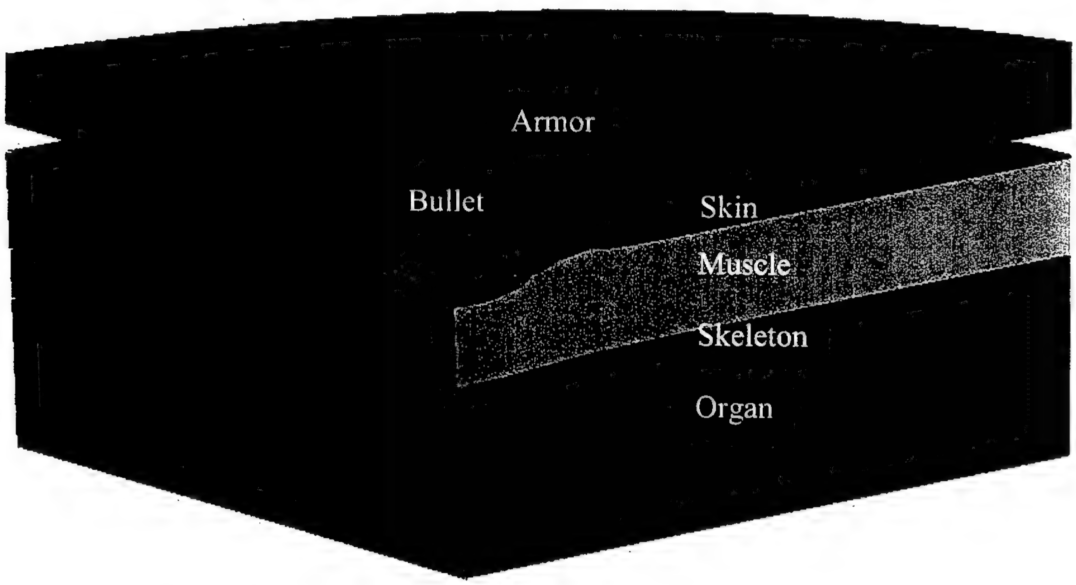
Comparison of finite element simulation of a nonlethal projectile impact against the thorax. Internal pressure within the lung has been previously shown to correlate with lung contusion for blast. These results show that the same mechanism is at work in projectile impact and can be predicted by the model.

Product 11: Stuhmiller, J.H. (2000). Modeling of Blunt Trauma Injury, Jaycor presentation to AIBS Review Panel, Washington, DC, Aug. 22, 2000.

4.2 Analysis of Behind Armor Ballistic Impact

As a result of the AIBS review, MOMRP requested that the STO-K effort be focused on the blunt trauma created behind personal body armor. Jaycor developed a modified planned effort accordingly. In anticipation of an FY02 start of the revised STO-K effort, Jaycor has begun research in three aspects of the problem. First, existing test data from a 1996 USAARL study and a 2000 NATO study, both investigating injury to swine behind hard armor, was collected and analyzed to determine estimates of loading, motion, and injury modes. Preliminary analysis indicates that the primary injury is lung contusion and

isolated rib fracture, and that the lung contusion is consistent with our previous chest wall velocity-dependent injury criteria. The measurements of acceleration and pressure have questionable aspects and may not be accurate in this violent environment, but the indications are that the loading is delivered to the thorax within one millisecond and over an area about 10 cm in diameter. Next, a simple finite element model has been constructed to simulate the bullet-armor-body interaction. The simulation is able to capture the qualitative aspects observed in the tests and leads to estimates of local lung contusion. Without quantitative data about the true nature of the loading, however, the simulations are only suggestive. Consequently, the third aspect has been to develop an impact-measuring device rugged enough to survive ballistic impact, yet able to measure the force distribution in both space and time. A prototype load measuring device is under construction.

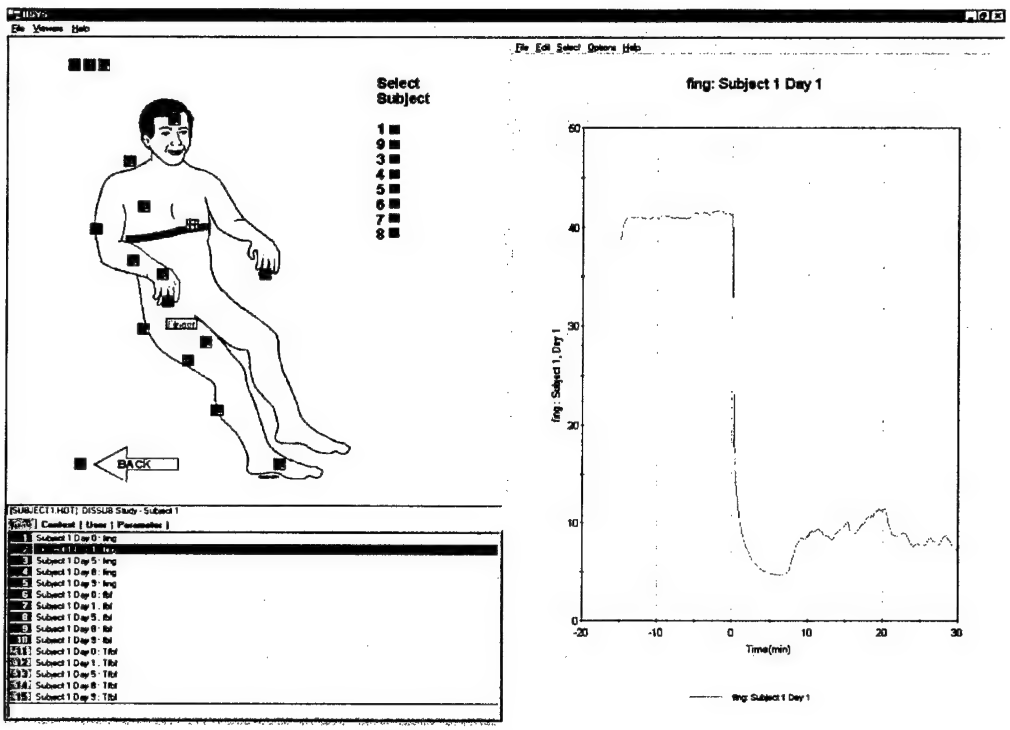


Finite element simulation of impact of bullet against a local region of the thorax covered by ballistic armor

5. STO-U: Fusion of Models

5.1 Disabled Submarine Study Database

An IISYS session was put together and delivered on August 18, 2000 for the Disabled Submarine Study (DISSUB). It included data for all tests conducted and each subject, database entries, pictures and a report documenting the data reduction method used by Jaycor.

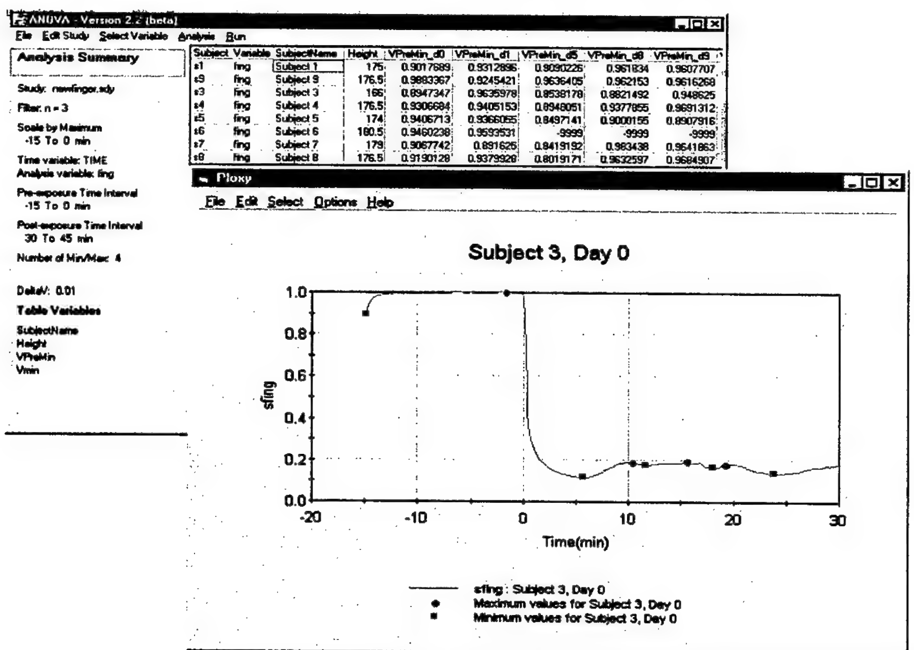


View of IISYS context-based presentation of one finger immersion test that was conducted during the DISSUB study. The upper panel on the left provides a pictorial context for locating all of the data collected for that subject. Where one physical location contains many individual data records, a list appears in the lower left panel. The panel on the right displays the selected data, in this case, the temperature of the finger immersed in cold water. The characteristic oscillation in temperature is a measure of the body's thermoregulatory response.

Product 12: Long, Diane, W. (2000). "Data Organization and Processing," Jaycor Report J3150.42-00-150.

5.2 Software Tools for ANOVA

In the analysis of data from cold exposure tests, it is necessary to examine analysis of variance based on quantities computed from time history data (for example, the time of minimum temperature in a finger immersion study). Often, those quantities must be determined with a complex analysis in one program and then transferred to another program where the statistical analysis is made. If the formula for the computed quantity changes or if the same formula is to be used in a new study, the entire process must be repeated. Jaycor wrote a program that automatically computes these quantities from the data and places the results in a matrix form ready for statistical analysis. The parameters of the calculation can be changed easily and graphical display of the calculated results can be compared with the original data to ensure that the correct quantity is being determined. The software is used by Dr. O'Brien of USARIEM to analyze thermoregulation studies.

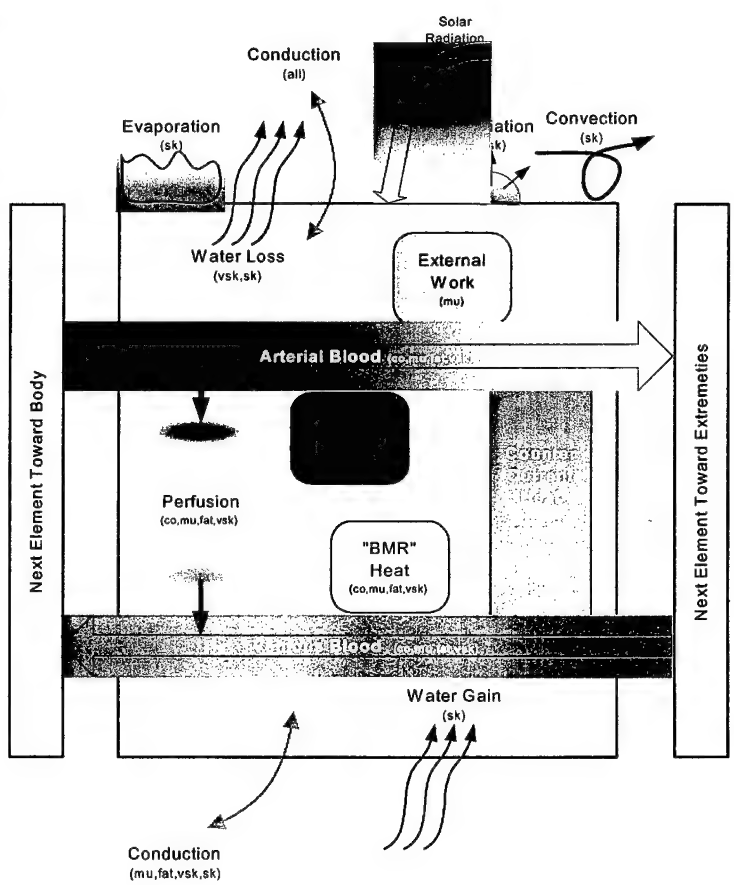


Computer screens from the analysis software ANOVA. The user can specify quantities to be analyzed from time trace data – in this case the time of occurrence of local maxima and minima in the finger temperature record. The program automatically returns the time trace for each subject-test combination, computes the desired quantities, and formats the data in tables ready for statistical analysis. The user can conform the accuracy of any of the table entries by double clicking and viewing a graphical display.

Product 13: ANOVA Software

5.3 Thermoregulation Model

In support of the USARIEM modeling effort, Jaycor has begun to construct a MatLab SIMULINK model of human thermoregulation. This model will be compatible with the physiologically based model being developed for STO-Y and will be a superset of the SCENARIO model. A literature survey was conducted in order to identify which physiological processes are most important in thermal regulation and to identify with current research and modeling efforts. Some of the models studied implement a very simple geometry in order to reduce the complexity and time requirements of computations. Others eliminate geometry altogether and simply solve a number of regression models, which have been derived from empirical data. While these achieve the desired speed and reduced complexity requirements, they cannot be expected to predict transient response as accurately as a more physiologically comprehensive model. We identified one recently developed model that addresses the geometric issues quite well, however it was developed for prediction of *comfort* and does not account for certain physiologic processes (substantial water loss, etc.) that may accompany high levels of thermal stress. A "best of breed" thermoregulatory model should allow for an accurate geometric representation and should include modeling of all known important physiologic responses. It should also be designed such that future refinement is not only possible, but possible in a controlled manner so that model integrity is maintained.



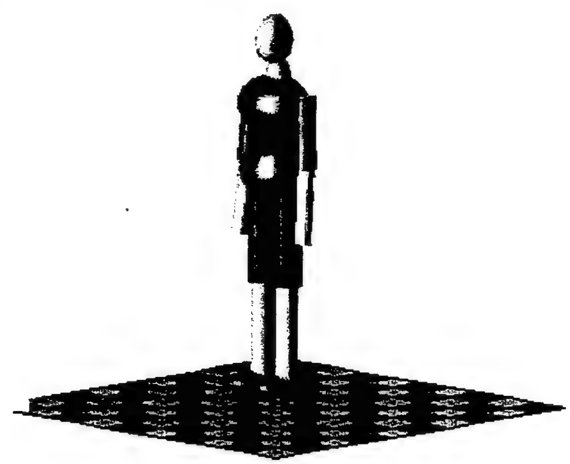
Schematic diagram of some of the elements that must be included in a comprehensive simulation of the human thermoregulatory system. The final schematic and review of literature for models, mechanisms, and data will provide the starting point for the model construction.

6. STO-W: Optimization of Physical Performance

6.1 Articulated Human Body Model (AHBM)

In the first phase of a project to develop an articulated human biomechanical modeling toolbox (AHBM), a review the status of current modeling techniques was made and a rigid body formulation suitable for human biomechanical modeling was developed. AHBM version 1.0 consists of kinematics, inverse and forward dynamics algorithms, data conversion routines, graphical algorithms, and many utility routines for mathematical calculation and file operation. Inverse and forward 3D models of the lower extremities, a whole human body, and a human head-neck were developed.

Visualization of articulated model of the human lower extremities



Visualization of whole body articulated model used in simulating blunt impact reaction

Product 14: Shen, Weixin (2000). "Articulated Human Biomechanical Modeling Toolbox, Part I: Overview, Rigid Body Formulation, and Examples." Jaycor Report J00-3150.31-135.

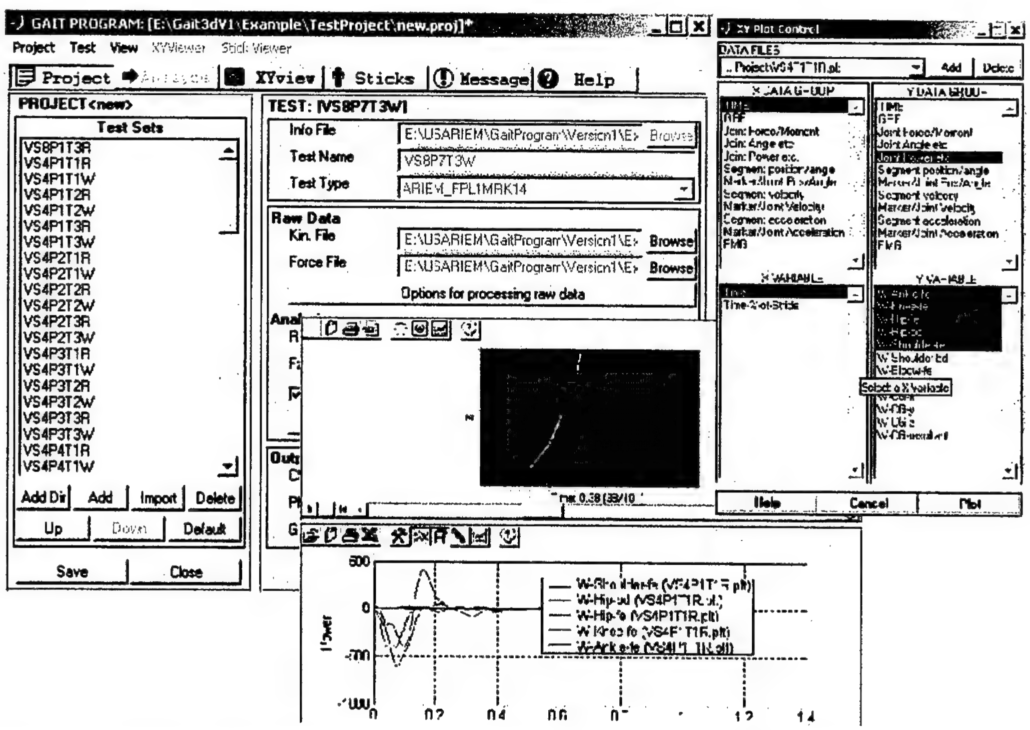
Product 15: Shen, Weixin (2000). "Articulated Human Biomechanical Modeling Toolbox, Part II: Toolbox Routines." Jaycor Report J00-3150.31-136.

Product 16: AHBM V1 software, an articulated human biomechanical modeling toolbox

6.2 Gait Analysis Software

The kinematics, inverse dynamics and graphical algorithms of the AHBM toolbox are used to develop a three-dimensional gait analysis program for the U.S. Army Research Institute of Environmental Medicine (USARIEM). The version-1 of the program, Gait3D V1 supports the current test setup of USARIEM motion analysis system. Input and output file formats currently used by USARIEM are fully supported.

Gait3D V1 allows running, visualizing and analyzing multiple gait tests in a simple graphical layout. It supports running multiple tests in one project and provides easy control of analysis parameters. Gait3D V1 also comes with the StickViewer and XYviewer developed in the AHBM toolbox. These viewers allow the visualization and animation of test results.



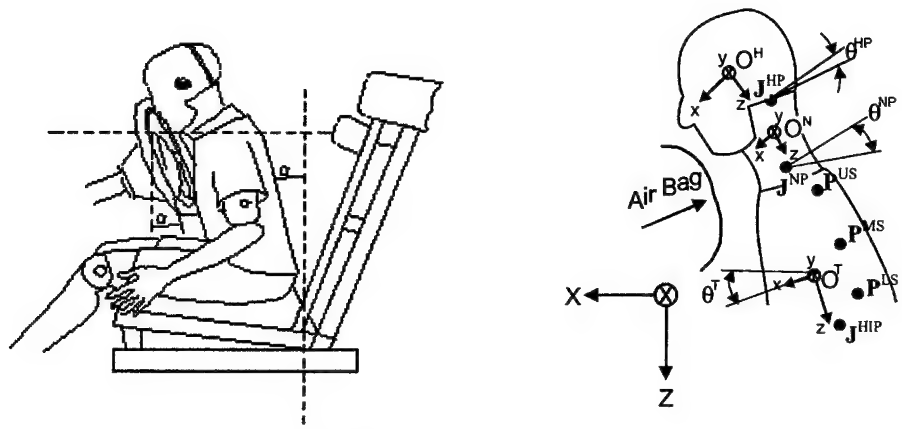
Composite of computer screens presented by the Gait3D software. The user can control details of the model, placement of the kinematic markers, and format of the output variables. The simulation can be viewed as a 3D representation or quantities plotted versus time.

Product 17: Shen, Weixin (2000). "Gait3D User's Manual: Version 1.0." Jaycor Report J00-3150.31-134

Product 18: Gait3D version 1.0 software

6.3 Inverse Model for Predicting Airbag Forces

An inverse dynamics model is developed for calculating external air bag loads on the head and neck of a small female test dummy using recorded dummy response data. This work was sponsored by the Department of Transportation, as part of the joint MRMC-DOT working relation, to understand and minimize the possible hazard of air bags based on physical principles.



Tests are conducted by the DOT to determine the kinematic motion of test dummies impacted by an inflating airbag. The actual loading of the airbag on the dummy cannot be measured. The inverse dynamics model, based on the articulated toolkit, performs and inverse dynamics analysis to determine the force responsible for the observed motion.

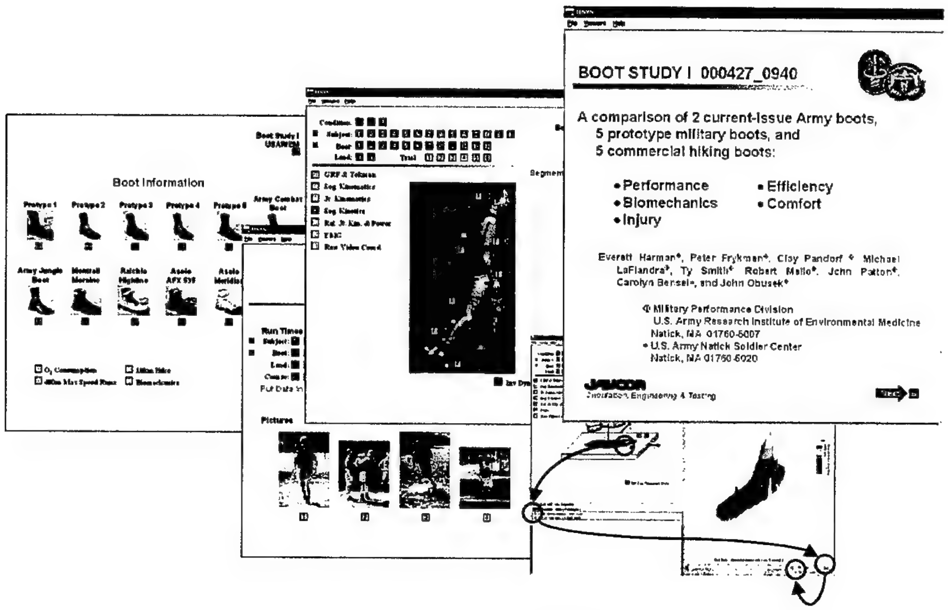
Calculations are performed for static out-of-position tests as well as vehicle crash tests. The calculated external loads provide a phenomenological explanation of the differences in dummy responses between different dummy positions. It is also shown that the impact angle on the head affects the head/neck joint load significantly.

Product 19: Chan, P. C., Shen, W. and Bandak, F. A. (2000), "Analysis of Air Bag Loads by Inverse Dynamics." Biomechanics Research: Experimental and Computational, Proceedings of the Twenty Eighth International Workshop.

6.4 Organization of Boot Study Data

USARIEM recently completed a large study to evaluate 12 boots for performance, efficiency, biomechanics, comfort, and injury. Fourteen subjects hiked, ran, walked, and jumped while various measures of boot performance were collected, including some force plate and kinematic data. This experiment generated over 10,000 files and requires more than 4.7 gigabytes of storage for the original data set. The objective of the Jaycor project

was to provide an archival organizational scheme for the data that takes advantage of specialized software to easily select, view, analyze and present the information from Boot Study I. In addition, a three-dimensional surface viewer was created to plot plantar pressures in an IISYS session and the IISYS database viewer was upgraded to be more user friendly.



Composite of computer screens from the IISYS context-based session for the Boot Study I data set. Almost 5 GB of data can be accessed readily with the selection of parameters from the context screen. New viewers were developed to visualize new data types, such as the Tekscan pressure sensors. The access to this data will facilitate exploration of more findings.

Product 20: Boot Study I: Data Organization and IISYS Session (8 CD's)

Product 21: Sih, B. L. (2000). "Boot Study I: Data Organization and IISYS Session User's Manual." Jaycor Report J3150.32-00-126.

Product 22: Surface Viewer 1.0: an IISYS compatible 3D plotting program for Tekscan sensor data.

6.5 Preliminary Analysis of Trends in Boot Study Data

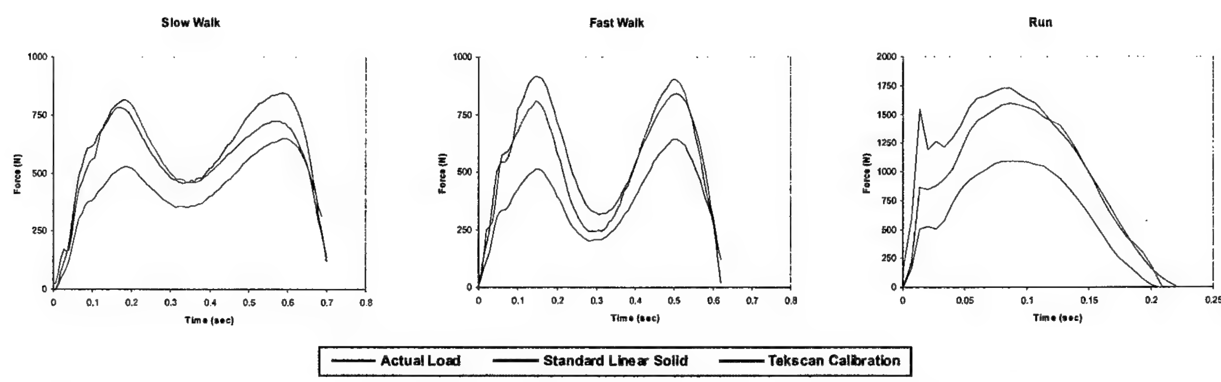
Preliminary analysis of the Boot Study data revealed interesting trends in the ratio of maximum plantar force with and without backpacks. Additional study may be warranted since maximum plantar force is related to the stress delivered to the lower extremities and, consequently, to the potential for injury. Results were discussed with USARIEM.

6.6 Improving Accuracy of F-Scan Sensor

While the F-scan system is capable of accurately recording relative pressures, errors up to 62% in total load are possible. This study examined the sources of error by analyzing the currently prescribed calibration method, characterizing the sensor both in and out of a shoe, and studying the long-term durability of the sensor.

1. The creep-like behavior of loaded sensels caused calibration errors that contributed to total load errors exceeding 30% during walking and running trials.
2. The surface conditions inside the shoe had altered the F-scan sensor properties.
3. A standard linear solid (SLS) model can reasonably approximate the plantar forces from an F-scan sensor output.
4. Compared to Tekscan's prescribed calibration method, mean error was reduced from 31% to 11% using the SLS model.
5. Sensor longevity was also investigated and the results suggest that overuse causes the gap between the two load-bearing surfaces of a sensel to collapse.

The results of this study indicate that the accuracy of the F-scan system is compromised by its viscoelastic behavior, causing errors during calibration and data collection. Applying a properly calibrated standard linear solid model to the F-scan output substantially reduces the error. This reduction may allow the collection of ground reaction forces accurate enough for predicting overuse injuries. The next step should be additional studies to confirm these results and to increase the complexity of the standard linear solid model to further improve on the F-scan accuracy.



Plantar force variation during a stride for three rates of gait. The forces are significantly underestimated by the sensor calibration provided with the Tekscan sensor. When the sensor output is interpreted by a standard linear solid model, much of the time force can be reconstructed.

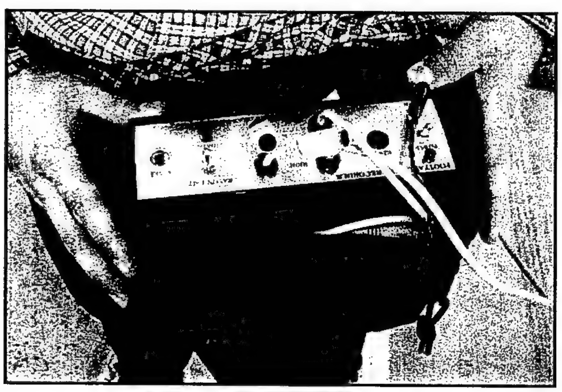
Product 23: Sih, B. L. (2001). "Improving accuracy of the F-scan sensor." Jaycor Report J3150.32-01-143.

6.7 Portable Data Logger for F-Scan

The portable system is designed to temporarily store left and right shoe F-scan sensor output in a transportable memory system, which can be downloaded to a computer at a later time.

- Data can be collected from either a single foot or both feet.
- The current system can store 4096 frames of data per foot, enough for 40 seconds of data when sampling at 100 Hz.
- A safety mechanism can be implemented to prevent accidental erasure of the data.
- The storage unit is approximately 180 × 206 × 64 mm and weighs 2.3 kg with batteries
- The storage unit fits comfortably in a hip-type pack.

The system's small size and weight allows non-laboratory data to be collected with a minimum hindrance to the subject. The battery life of the current system is untested but data was collected for approximately 20 minutes with no measurable power loss. Battery life during data storage is substantially longer (2+ hours).

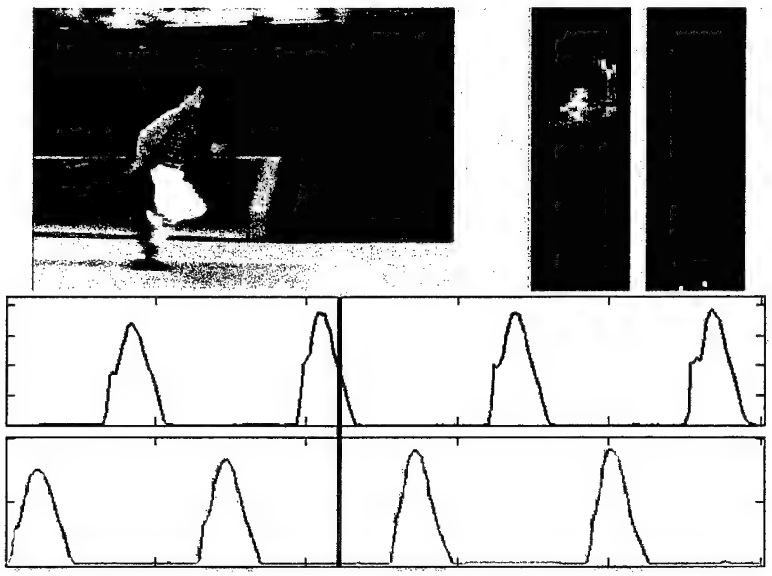


The portable data logger is packaged in a metal case, including battery power, that is carried in a hip pack. The unit can record 40 second intervals of data from both feet, which are then downloaded to a computer. Current battery life is more than 2 hours. This unit will allow foot contact data to be collected in field conditions that have never been possible before.

Product 24: Portable Data Logger for F-Scan System

6.8 Application of a Portable F-Scan System

Currently, the F-scan system is "tethered" to a PC-compatible computer with 10-meter cables. The portable system developed by Jaycor, Inc. is designed to temporarily store F-scan sensor output in a transportable memory system, which can be downloaded to a computer at a later time. To demonstrate the capabilities of the portable system, plantar pressure data was collected from a subject performing a variety of movements that would have been impractical or impossible to measure using a nonportable system.



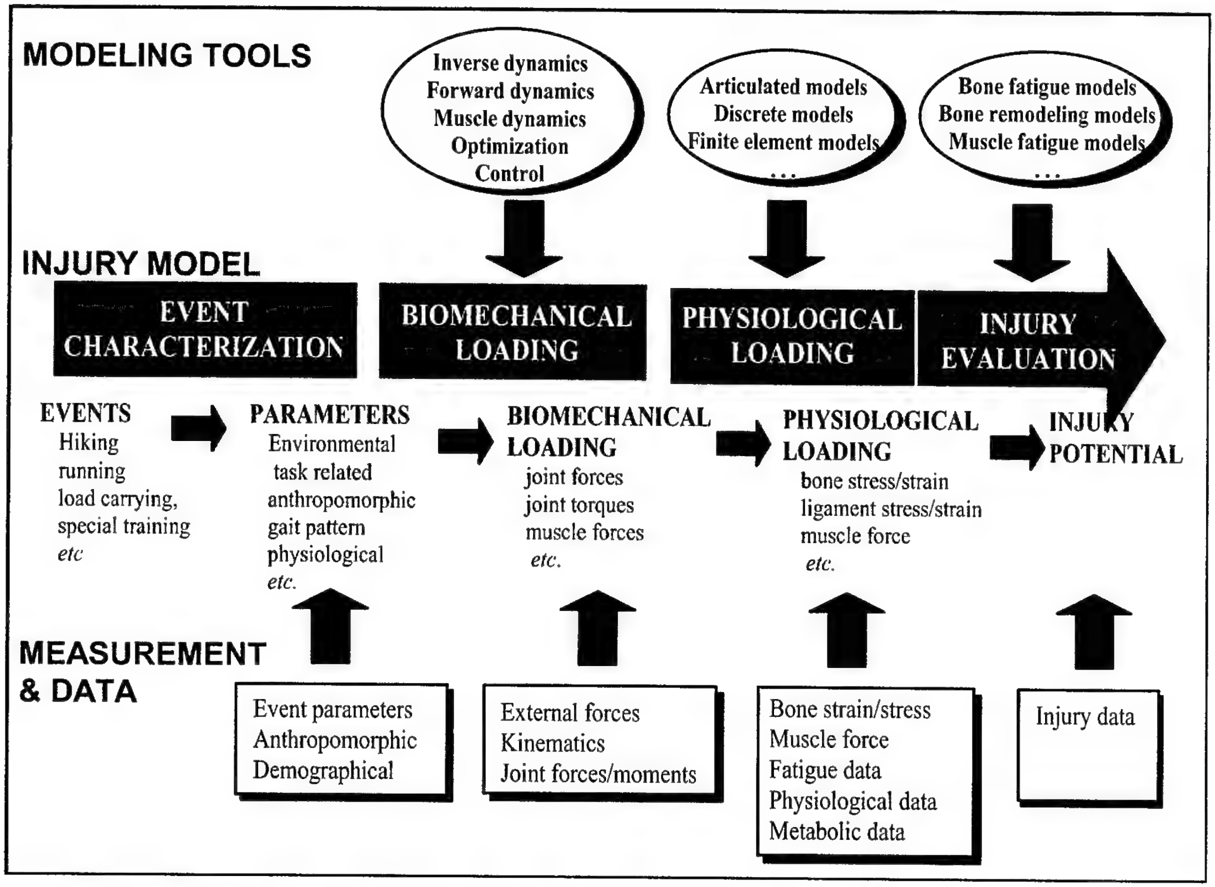
Data collected with the portable unit while running uphill.

Product 25: Sih, B. L. (2001). "Application of a portable F-scan system." Jaycor Report J3150.32-01-145

6.9 Overuse Injury Assessment Model

Overuse injuries in military training represent a high cost in both lost days and medical expenses. Over the past decade, there has been a considerable amount of research into the biomechanics of gait, the mechanical basis of injury, and the mechanisms of the physiological response to periodic stress. It appears that most of the pieces now exist to produce an integrated model of overuse injuries that can be used in assessing risk in the population and evaluating equipment and training. To demonstrate that such an integration is possible, an example calculation is made using estimates of loading, bone damage and remodeling, and the statistical aspects of failure. This very preliminary model

quantitatively shows how the various training, physiological, and population-related parameters interact. Agreement with training data is encouraging.



Schematic diagram of the interaction of models and data to produce an estimate of lower extremity overuse injury.

Product 26: Shen, W., Sih, B. L. and Stuhmiller, J. H. (2000). "Overuse Injury Assessment Model." Jaycor Report J7520-00-127.

7. STO-Y: Inhalation Injury and Toxicology Models

The US Army Medical Research and Materiel Command (MRMC) has responsibility to conduct research that will support the assessment of immediate incapacitation and injury caused by acute exposure to toxic gases, particles, and aerosols. The assessment must account for physical activity, environmental conditions, and complex mixtures of gases. The Military Operational Medicine Research Program (MOMRP) is conducting a research program to develop a mathematical model of the physiological response to acute toxic gas exposure that will provide a standard means to estimate these effects. That program is called Scientific and Technical Objective Y: Inhalation Injury and Toxicology Models.

The model will be developed in incremental steps. The first version of the model will provide a means of estimating immediate incapacitation in man, employing empirical relations for key physiological processes. Successive improvements to the model will add more complete physiological models of breathing, blood, chemistry, airway transport and deposition, metabolism and so forth as required to capture the necessary mechanisms.

The technical approach to achieve this objective is to (1) assess the literature for mechanisms, models, and data pertinent to the particular phase of model development; (2) implement mathematical models incorporating those mechanisms and validate by those data; and (3) conduct animal studies to provide missing physiological parameters or needed confirmation results. This approach will be repeated for each increment of the model development.

7.1 Small Animal Laboratory Testing

A number of rat tests have been performed to provide detailed quantitative data on ventilation changes during toxic gas exposure. The matrix of tests conducted is shown below. This activity has now transitioned to WRAIR.

Test	O2 (%)	CO2 (%)	CO (ppm)	NO (ppm)	NO2 (ppm)	# Subjects
38	20.5		1000			5
40	20.5	0.3	3250			5
42	20.5	0.2	6250			5
44	21.0		12,300			5
47	20.5	5.0	3,200			5
48	21.0	5.0	1,200			5
49	21.0	5.0	500			5
50	20.5	5.0	6,200			4
51	ng	5.0	12,000			5
52	21.0	5.2	12,300			3
53	21.0	5.2	12,700			2
66	20.0	4.9				6
67	20.0		6,000			4
68	21.0				475	6
69	21.0					6
70	21.0	trace				6
71	21.0	trace				6
72	20.5	10.3				8
73	20.5		3,000			6
74	15.0					6
76	12.0					8
77	15.0	5.0				8
78	21.0	5.0				8
79	12.0					6
80	50.0					6
81	97.0					6
82	98.0					6
83	20.5		12,000			6
84	21.0				1,000	6
103	20		12,000			6
104	21	5.2	12,000			6
105	21		23,000			6
106	21	5 and none	12,000			6
107	21	5 and none	12,000			6
108	21		3000, 30min			4
109	21		10,000 and 12,000			8
110	21		24,000			8
112	21				2000	5

Matrix of rat exposure tests conducted by Jaycor measuring ventilation changes.

7.2 Breath Analysis Algorithm

A breath identification algorithm was developed to make quick computation of summary values (such as minute volume) possible. Our first implementation was "rule based", looking for specific patterns in the data. We found that this approach failed any time a new pattern in the data emerged and thus needed constant refinement. The current implementation utilizes a combination of moving average and Butterworth filters to first smooth the data so that key points can be identified. By definition, the point at which gas flow rate is zero is a transition from inhaling to exhaling or vice versa so our first key point for identification of breaths is this axis crossing. The following figure shows how our algorithm initially identifies axis crossings.

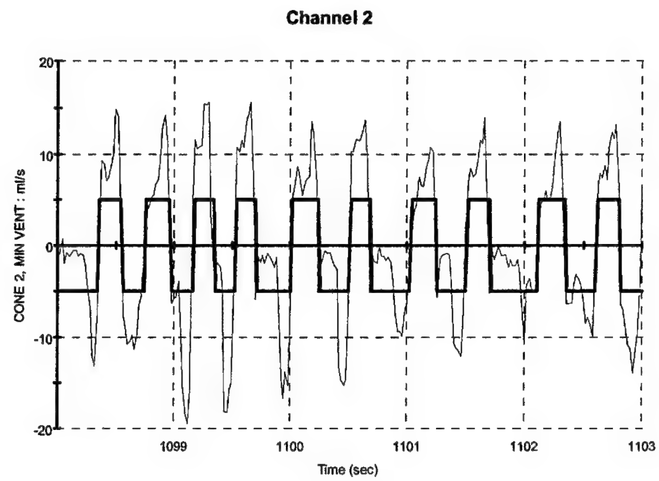
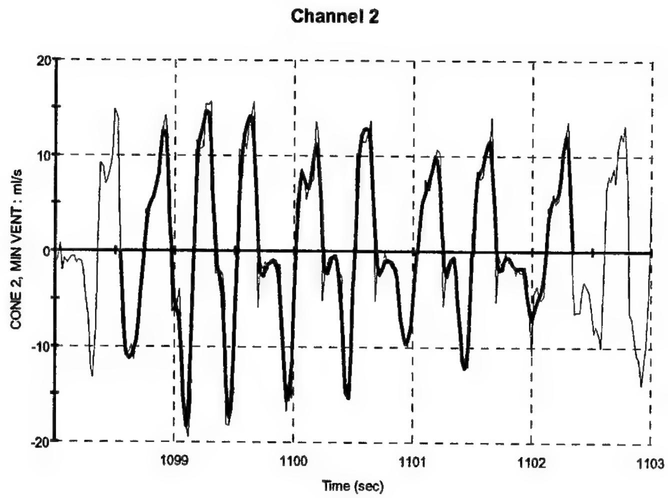


Illustration of the breath analysis algorithm capturing the exhalation and inhalation/pause intervals of each breath. The algorithm has proven to be robust in normal, panting, and hyperventilation conditions.

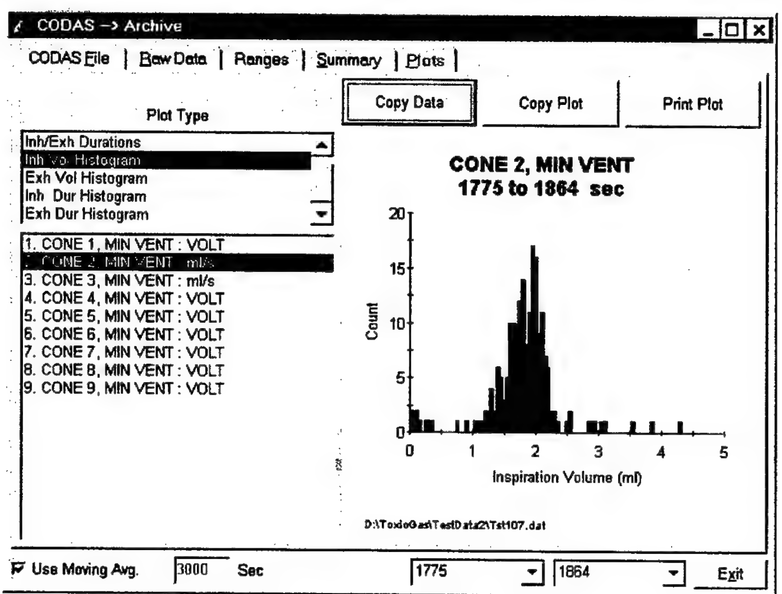
With the initial key points identified, we may then begin to refine our results using heuristics or rules. Inhalation and exhalation peaks are identified by again applying a Butterworth filter to eliminate events of very short duration which may be false peaks, and then finding a local maximum or minimum. Pause segments of the breathing cycle are identified by inflections between the exhale cycle of one breath and the inhale cycle of a subsequent breath. The final result (see below) is a set of clearly identified breaths, including the inhalation (red), exhalation (green), and pause (dark blue) segments of a normal breath. Smoothed data is used only for *finding* breaths. For computation of summary values, actual data is always used so as not to modify any computational results.

The second step of the breath analysis separates the pause and inhalation portions. Each phase of the breath is then analyzed for time and volume and stride in instantaneous, 10-second, and 60-second averaged values.



7.3 ViewCodas Software 1.02

The ViewCodas software, that allows Codas data acquisition files to be processed automatically, was upgraded to include the new breath analysis algorithm and to automatically write GDIF files for each animal exposure condition. The user now defines three time ranges for each experiment: pre-exposure, exposure, and post-exposure. The software then automatically adjusts the time axis to zero at the start of exposure and computes all ventilation quantities in all three time ranges. The ventilation quantities that can be computed in 10-second and 60-second averages include inhalation, exhalation, and pause volumes and durations, minute volume, tidal volume, drive, and number of breathes.

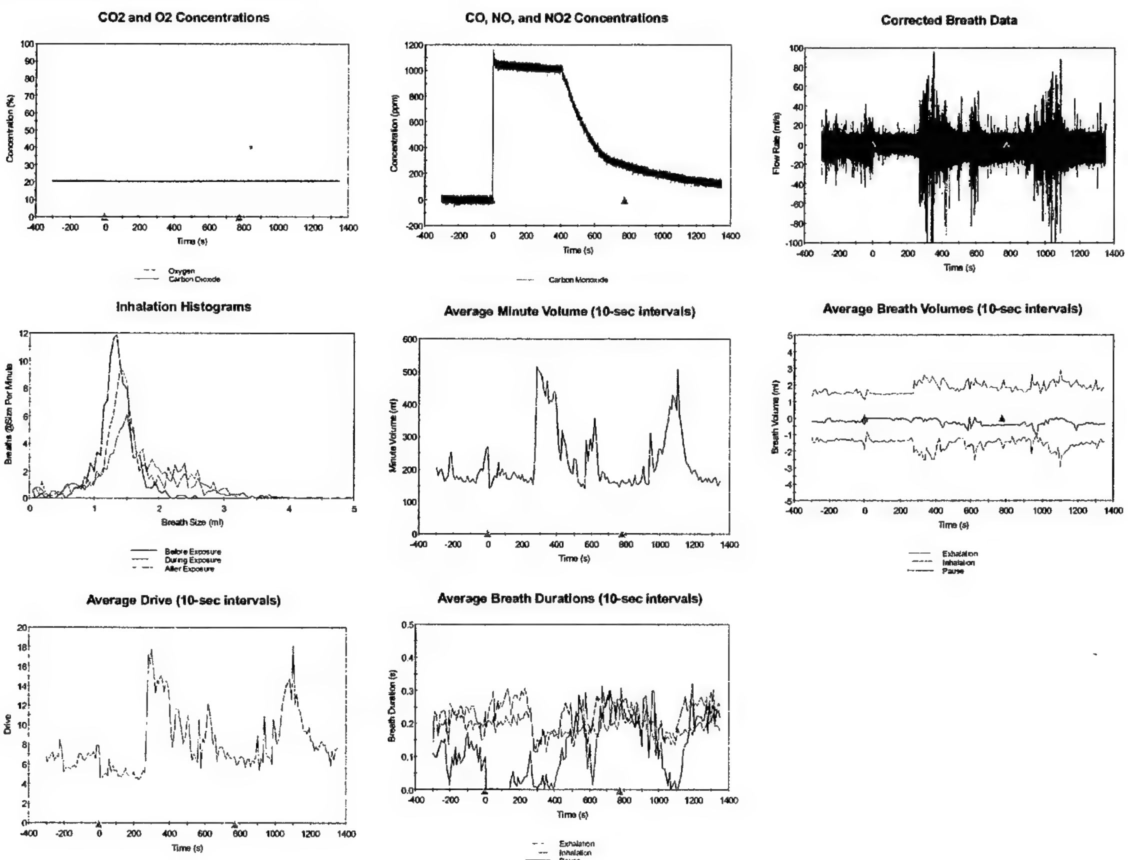


The ViewCodas software allows data collected on the codas system to be automatically processed to obtain quantities important to ventilation analysis. The processed data is then written to files for further analysis by programs such as MS Excel.

Product 27: ViewCodas software 1.02

7.4 Analysis of Small Animal Test Results

Because of the large number of experiments being dealt with, it was necessary to have a way of reviewing key portions of the data efficiently. Jaycor's PrintPlots application allows batch printing of any number of plots and can print multiple plots on a page. The data files exported from ViewCodas are a perfect candidate for this type of batch output because they all contain the same type of data. A template is first developed, fully specifying each plot that is to be displayed for a target data file. Eight plots were identified that would sufficiently summarize the data in each output file and these plots were defined within a single template for printing. By submitting this template and all of the data files to the printplots application, we end up with a single page of output (duplex printed) for each test which can then be bound into a document for future study and review. A sample of this output is shown below.



Example of test data automatically plotted

Product 28: Chilton, W. E. and Long, D. W. (2001). "Rat Respiration Data," Jaycor Report J3150.43-01-151

7.5 Immediate Incapacitation Source Book

The goal of STO-Y is to provide a model-based assessment of immediate incapacitation and injury caused by acute exposure to toxic gases, particles, and aerosols. The assessment must account for physical activity, environmental conditions, and complex mixtures of gases. The model will be developed in incremental steps. The first version of the model will provide a means of estimating immediate incapacitation in man, employing empirical relations for key physiological processes. This task provides a synthesis of the literature on toxicity from inhalation of gases, with an emphasis on mechanisms, data, and models dealing with immediate incapacitation. This review provides the guidance for developing the first mathematical model in the series, TGAS 1.0, which will provide an estimate of immediate incapacitation from acute exposure to complex mixture of toxic gases. The results are present in tables for all major studies and for study-to-study comparisons.

Lethal blood CN^- (mg/L) Swiss Webster mice Esposito and Alarie (1988) (Fig. 2, 4, 6, 11)				
	Mean lethal blood CN^- (mg/L) at LC_{50}	**Mean Lethal %COHb**	**LC_{50} LT_{50}**	**Additive factor**
HCN (131-266 ppm)	0.95 ± 0.17 mg/L (0.75- 1.16 mg/L)		LC_{50} 177 ppm (157- 199 ppm) LT_{50} :29 min	
HCN (88-118 ppm) + CO (1500 – 1997 ppm)	0.56 ± 0.09 mg/L (ranged 0.41-0.66 mg/L) (lethal CN^- level reduced 41%)	45% (37-51%)	HCN = 106 ppm (95-119 ppm) CO = 1815 ppm (1617-2036 ppm) LT_{50}: 32 min	1.2
HCN (80-106 ppm) + O_2 (13-15%)	0.59 ± 0.19 mg/L (0.23-0.91 mg/L)		HCN = 89 ppm (85-94 ppm) O_2 = 13.8% (13.5-14.2%) LT_{50} : 11 min	1.0
HCN (181 ppm) + CO (6060ppm) + CO_2 (5.5%) + O_2 (12.2%)	0.18 ± 0.10 mg/L	Lethal %COHb is at the lowest level for gas mixture with all 4 gases.		

Example of data summary table from Source Book.

Product 29: Stuhmiller, L.M. (2001). "Immediate Incapacitation Source Book." Jaycor Report J3150.12-01-113.

7.6 Immediate Incapacitation Data Book

The data relevant to validating the TGAS model have been extracted from the tables and figures in the literature, digitized, and place in a form for direct electronic access for Jaycor researchers. The data is summarized by document and contains links to the scanned document as well as to the tabulated data. The data is presented in tabular or graphical form, depending on the original form. An example is shown below.

Chaturvedi, A. K., B. R. Endecott, et al. (1993). "Variations in time-to-incapacitation and blood cyanide values for rats exposed to two hydrogen cyanide gas concentrations," DOT/FAA/AM-93/8, Oklahoma City, OK, 20, May 1993.

Rat No.	t_i (min)	HCN* (ppm)	Blood CN^- (μg/mL)	Rat No.	t_i (min)	HCN* (ppm)	Blood CN^- (μg/mL)
1	4.7	190	1.68	26	5.6	193	2.88
2	5.7	171	2.05	27	4.7	198	2.74
3	5.0	161	1.79	28	4.5	202	2.66
4	5.3	181	1.55	29	7.0	182	3.41
5	4.9	181	2.11	30	5.5	183	2.72
6	4.2	177	2.16	31	4.7	186	2.66
7	7.5	181	1.89	32	4.8	188	2.48
8	4.9	190	1.52	33	4.8	178	2.42
9	4.3	178	1.87	34	5.0	179	2.42
10	5.4	184	1.71	35	5.9	173	2.19
11	5.3	184	2.08	36	5.0	190	3.01
12	4.5	187	2.53	37	5.6	179	2.77
13	4.5	193	1.95	38	4.0	191	1.84
14	5.3	193	2.19	39	4.7	192	2.24
15	4.4	181	1.52	40	4.6	197	2.61
16	4.9	171	2.29	41	4.4	202	2.42
17	5.6	159	2.11	42	4.8	190	2.80
18	6.6	163	2.98	43	4.5	188	1.87
19	6.8	165	1.95	44	5.6	188	2.13
20	6.6	168	2.19	45	4.1	193	2.56
21	4.6	188	2.88	46	4.5	180	1.89
22	4.2	185	2.64	47	5.0	184	2.37
23	7.1	181	3.01	48	4.9	200	1.52
24	5.1	188	2.24	49	4.4	183	2.11
25	5.0	190	3.70	50	4.7	180	1.52

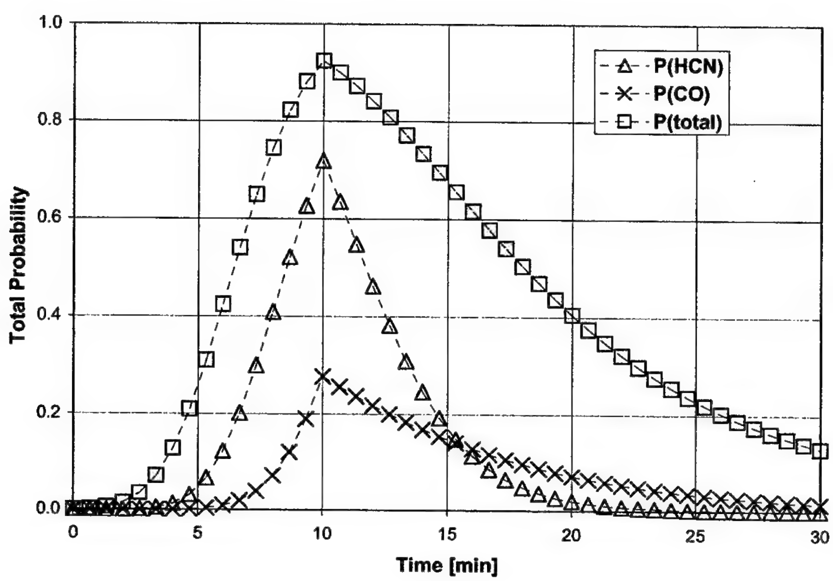
Example of data retrieved from electronic database

Product 30: Stuhmiller, L.M. (2001). "Acute Toxic Effects Data Book." Jaycor Report J3150.12-01-138.

Product 31: Electronic Database with links to scanned documents [internal use]

7.7 TGAS 1.0

The TGAS1.0 model is based on a simplified representation of the inhalation, exhalation, and accumulation of toxic substances and is based on previous work sponsored by the Live Fire Test Program and MOMRP. The model estimates of the ventilation rate, accounting for species differences, activity level, and chemically induced physiological response. Incapacitation is assumed to occur in all species when a critical internal dose is reached, corresponding to the ratio of mass absorbed to body mass. The probability of incapacitation is obtained from population variations observed in animal tests. The interaction between gases arises primarily from the alteration of the common ventilation rate and, in the few instances where combined gas effect data are available, from estimates of internal dose interactions. The model estimates the probability of immediate incapacitation as a function of time for any combination of seven gases: carbon monoxide (CO), hydrogen cyanide (HCN), nitrogen dioxide (NO_2), hydrogen chloride (HCL), acrolein, reduced oxygen (RO_2), and carbon dioxide (CO_2). These are the only gases for which adequate incapacitation data exists.

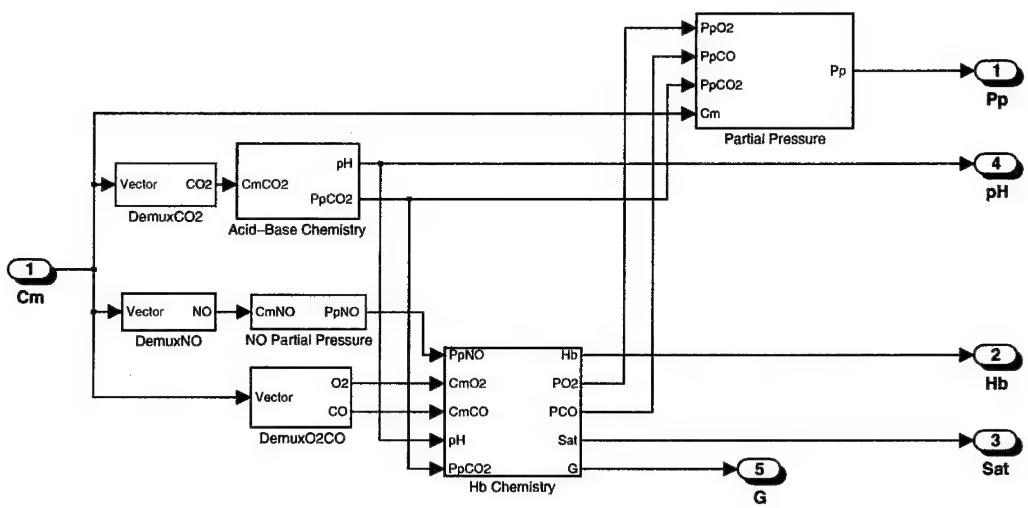


Probability of immediate incapacitation from individual gas components and from the total internal interaction. Exposure is 2000 ppm CO plus 150 ppm HCN for 10 minutes to a rat on a wheel (f = 2) followed by normal air.

Product 32: Stuhmiller, J.H. and Stuhmiller L.M. (2001). "TGAS 1.0 Model of Immediate Incapacitation," Jaycor Report J3150.12-01-139.

7.8 Conversion to MatLab SIMULINK

The future generations of TGAS will add complete models of the circulation, respiration, blood chemistry, and control of breathing to improve the ability to compute the internal dose and to allow a means to compute physiological and cognitive performance. To be able to efficiently and accurately incorporate, test, and validate such complex models, it is necessary to have a simulation environment that is robust and capable of dealing with such complexity. After evaluation of existing commercial software tools, MathLab's SIMULINK program was selected. Mathematical equations are cast into hierarchical block diagrams that are linked to form a complete model. Individual components can be interchanged, thus allowing competing submodels to be evaluated. The formulation, maintenance, and application of a SIMULINK model is very different from that normally encountered in lower level languages, such as C++ or FORTRAN, so a considerable effort has been invested into the infrastructure of the model. A working version of TGAS has been obtained that will now be systematically expanded, validated, and distributed.



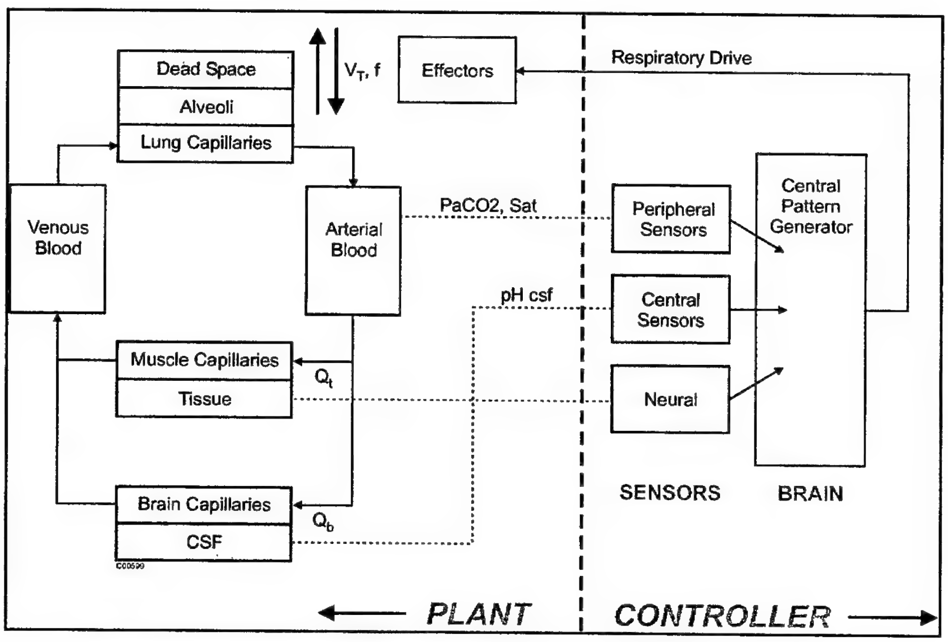
TGlib/Blood Chemistry1	d:\simulation\version1.2\TGlib.mdl

Example of SIMULINK subsystem description for blood chemistry determination. Subsystems describe the physical, acid-base, and hemoglobin reactions and interact with one another through common variables.

Product 33: Stuhmiller, J.H. and Stuhmiller L.M. (2001). "TGAS 2.0, Part I: Model Equations," Jaycor Report J3150.12-01-142. [in development]

7.9 Control of Respiration Source Book

TGAS 2.0 will be physiologically based, providing means to describe internal dose, interactions between toxic gases, and allowing species extrapolation and performance estimation. An accurate internal dose assessment requires a physiologically based breathing control model which estimates the ventilation changes as a function of the gas transport process, brain control mechanism, and sensor inputs. Several research groups have assembled comprehensive models of breathing control, each with slightly different component models and each applied to slightly different problems. The control of respiration involves the interaction of many of the body's major systems (ventilation, circulation, metabolism, blood chemistry, neural and muscular control) and therefore requires a complete, interacting description. A composite model, using the best parts of these models, provides the starting point for TGAS 2.0. This work provides a synthesis of the literature on control of breathing, with emphasis on identifying mechanisms, data, and models that are relevant to ventilation changes that can significantly impact acute inhalation exposures.



Schematic diagram of the model of the control of ventilation. Each box will be developed into SIMULINK subsystems for incorporation in the TGAS model.

Product 34: Stuhmiller L.M. (2001). "Control of Respiration Source Book," Jaycor Report J3150.12-01-141.

7.10 AIBS Review

In May 2001, a panel convened by the American Institute of Biological Sciences (AIBS) reviewed the WRAIR program plans for developing a model-based assessment of inhalation injury and toxicology, the STO-Y program. Jaycor prepared a summary of toxic gas inhalation modeling previously developed, the synthesis of current models and data that will guide the development of the model, and the planned contribution to the WRAIR program.

Product 35: Presentation: Stuhmiller, J.H. (2001). "TGAS 1.0: Model of Immediate Incapacitation," Jaycor presentation to AIBS Review, Washington, DC, May 18, 2001.

Product 36: Presentation: Stuhmiller, L.M. (2001). "Immediate Incapacitation," Jaycor presentation to AIBS Review, Washington, DC, May 18, 2001.

Product 37: Presentation: Stuhmiller, J.H. (2001). "TGAS 2.0: Physiological Models of Ventilation (Progress Report)," Jaycor presentation to AIBS Review, Washington, DC, May 18, 2001.

Product 38: Presentation: Stuhmiller, L.M. (2001). "Control of Breathing," Jaycor presentation to AIBS Review, Washington, DC, May 18, 2001.

8. List of Products